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# Urban form and function as building performance parameters

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## Abstract

The climate in cities differs significantly from those found in the surrounding area. These differences result from modifications of the Earth's surface that alters the disposition of "natural energy balance" at a micro-scale and the concentration of activities that results in anthropogenic emissions that change the composition of the atmosphere. These urban effects have distinctive temporal and spatial properties with different impacts on building energy performance depending on their purpose, which are rarely accounted for.

This paper examines performance implications of a change-of-use (from office to residential) in the context of the UK government's proposal to encourage regeneration and to meet housing needs. However, the diurnal occupation and activity patterns of these uses are distinct. For office buildings, with daytime occupation, focus is on the diurnal heating cycle driven by solar energy gains to which internal energy sources must be added. For residential buildings occupation and activity are primarily associated with the diurnal cooling period, and lower levels of activity that results in a primary heating need. This paper highlights the link between the timing of the urban climate effects, the urban setting and energy performance in a typical city street, where buildings are currently designed for commercial use. It employs London's current and projected climate to simulate heating and cooling demands. By studying the role of urban form and its implications on the suitability of a building's function we find that a 'form first' approach should be considered in the early design stages over the standard 'fabric first' approach.

## 1. Introduction

Under the Climate Change Act, 2008 [1], the UK government has committed to reduce CO<sub>2</sub> emissions by 80% by 2050 compared to 1990 levels. Meeting this target will require a range of measures that include building refurbishment to reduce the fixed consumption inherent to the building's fabric and conditioning systems (the regulated load). This regulated load is strongly dependent on both the function of the building (e.g. office or residence) and the climate to which it is exposed. In assessing the role of climate, observations from a standard meteorological station located in a 'rural' or non-urban environment are often employed. However, most buildings are situated in urban environments where the climate has been significantly modified as a result of the accumulation of micro-climate exchanges between surfaces when compared to the non-urban 'background' climate. At the street level these exchanges have specific effects on the energy performance of individual buildings, although there is no current UK legislation that requires these micro-scale effects to be taken into account. As a consequence, the energy performance of buildings and the potential from refurbishment is often examined for buildings as though they are situated in a stand-alone non-urban setting overlooking the urban climate effects on energy management.

The urban climate effect results both from changes to the Earth's surface that alters the natural energy balance and from the concentration of activities, the emissions of waste gases, liquids and particulates that change the composition of the atmosphere. Many of these effects are the result of decisions on building form (the shape of the envelope and the materials used in construction) and on building functions (the nature of occupation), which are often made in the context of neighbourhood scale planning guidelines. In other words, the urban climate is partly the aggregate outcome of decisions made at the scale of individual buildings, and although this will affect the performance of these buildings, is not included in the buildings evaluation. In addition, the background climate is itself undergoing change as a consequence of anthropogenic emissions of greenhouse gases, much of which is driven by the need to condition the indoor climate.

Policies around refurbishment help increase redevelopment rates (currently around 1-2% per annum [2]) are necessary if the UK government is to reach its commitment to lowering CO<sub>2</sub>. In this context, the UK government recently proposed that planning rules be relaxed to allow change-of-use from commercial to residential purposes without the need to obtain planning permission. The motivation behind this proposal was to address a housing shortfall, regenerate urban areas and 'recycle' the existing building stock toward sustainable development. The subsequent consultation identified three major concerns: the potential conflict with long term economic development; the suitability of the building footprint (employment buildings do not automatically lend themselves to residential functions) and; the appropriate location for such changes [3,4]. Nevertheless the UK Department for Communities and Local Government (DCLG) have recommended that, where a housing 'need' is identified, approval for change-of-use should be encouraged [5]. However there are energy management implications associated these changes that could result in additional and costly energy efficiency optimisation measures that have not been considered.

Whilst the urban climate is recognised to influence building performance over the background climate (e.g. Watkins and Kolokotroni) [6,7], an effect which is expected to become increasingly significant with warming trends [8], to date, there has been no evaluation of the synergistic impact of climate change, the urban effects and change-of-use on building energy management. In addition their likely effect on achieving target reductions also remains overlooked. The work presented here examines building energy performance within an urban context and examines the implications for performance when buildings undergo a change-of-use from offices to residences. This research takes a 'form first' approach to building energy management by focussing on the urban context as a management parameter rather than the efficiencies (the regulated energy and the operational loads) of the building systems themselves for both current and future climates.

## **2. Background**

From the perspective of buildings, the urban climate effect is to modify energy exchanges across the building envelope when compared to a non-urban setting. These modifications result from the nature of the urban morphology and fabric. These parameters restrict airflow movement below roof level, intercepts solar radiation causing overshadowing and permits long-wave radiation exchanges between building surfaces. In addition, the dense and impermeable manufactured materials that comprise much of the urban setting have distinctive radiative and thermal properties. As a consequence, the external gains and losses of an identical building will vary according to its position in the urban setting and its juxtaposition to the surrounding buildings.

One of the most extensively studied urban climate effect is the urban heat island (UHI), of which there are several types. All UHI types are strongest under clear skies and calm winds when

radiation exchanges at the surface and changes in the substrate heat storage dominate. The surface UHI is often measured using satellite imagery and shows the observed urban surface (roof and street surfaces) as warm, when compared to the surrounding setting. Its magnitude is greatest during the daytime but this picture is more complex when the full three dimensional surface, which includes building walls, are taken into account. Within the urban canopy (that is, below the rooftop level) the patterns of shadow and sun- light create a highly variable surface temperature map, with very large differences occurring over short distances. There is also a canopy level UHI that is usually measured as the difference between the air temperature recorded in the urban area and that observed at a nearby site, outside the urban area (often referred to as 'rural'). The difference is greatest at night under calm and clear conditions as urban surfaces cool slowly after sunset, compared to non-urban sites. For any city the magnitude of this UHI is largest in the urban centre, which is usually characterised by little vegetative cover and tall buildings. Hence the urban land-cover typical of mid- latitude cities, which proceeds from green suburbs to a dense core, results in a UHI gradient. During the day, this UHI is weak and may even be negative in the urban core where taller buildings inhibit solar access at street level and impedes warming.

These urban climate effects interact with building energy systems that are designed to manage the internal and external gains so as to create an indoor climate suited to its function. For central urban areas it is these levels of solar receipt at the surface and the dynamic nature of mutual shading between buildings that can directly affect both the outdoor and indoor climate and therefore the associated building heating and cooling demands [9]. For buildings with daytime functions there is usually a cooling load, which can be managed by limiting solar energy gain. On the other hand, if the building were occupied in the evening hours when heating loads are an issue, maximizing solar access is a worthwhile strategy. These patterns of use correspond closely to office and residential functions, which have almost opposite activity and occupation patterns. As a result they coincide with different parts of the diurnal climate cycle (office function with daytime heating and residential functions with night-time cooling) and different urban climate effects. While the consequence of the diurnal cycle on building performance can be managed through optimising the building fabric and operating systems, this does not account for the influence of the urban context.

The influence of urban form and function on the background climate for the most part remain in the realm of urban climatology, however there have been some studies outside this discipline that have examined the role of form and function as an energy management parameter [6,7,10e14]; Wong et al., simulated a single three-storey, air conditioned warehouse/office building for the tropical climate (Singapore) over one day using 32 scenarios representing different urban settings. The results show increasing the height of the surrounding system lowers outdoor temperature and reduces cooling load by around 5%, which over a large urban area can be significant. Lam simulated the performance of two identical buildings, with and without shading, for Hong Kong, and found for peak design conditions the shaded building had a 14% reduction in cooling demand. Ali-Toudert examined the performance of a single building in different urban settings, with various building properties, for three different climate regions, and found that cooling needs decrease with deeper street canyons. Krüger et al. also found that mutual shadowing provided by adjacent buildings improves the performance of a single building in a hot arid climate, whereby cooling demands were reduced with increased surrounding building height. Strømman-Andersen and Sattrup found that the energy performance of low-energy buildings in a north-European setting is affected by the geometry of urban canyons within the range of up to 30% (offices) and 19% (residential), demonstrating the urban form as a key factor in energy use in buildings. Finally, in a mid-latitude environment, various studies undertaken by Watkins et al. and Kolokotroni et al., compared the performance of a hypothetical office building placed in different parts of London against the identical building placed in a rural environment using

measured air temperature data. The results show cooling load to increase towards the city centre with increasing air temperatures, but also notes that buildings that receive higher levels of over-shadowing to show a reduction in cooling load. Each of these studies focus on the performance of the single building in an urban setting and demonstrate the relationship between urban form and urban climate as a positive energy management parameter. However the interdependent relationships and the timing of the various urban climate effects remains overlooked.

In other work by the authors [15] canyon geometry was shown to be a significant energy management parameter for buildings with daytime occupation in central London. These buildings had a significant daytime internal gains as a result of office-related functions, which when added to the external gain obtained primarily through the glazed facade, generated a load dominated by the need for cooling. Modifying the street canyon form by varying the building height provided greater shading of the glazed facade and acted as an urban 'solar umbrella' [16]. The simulations were limited to daytime conditions and office building types. Whilst average building height (H) by the width (W) of the street that separates them (H/W ratio) is an established description of urban morphology that has been used to study outdoor energy exchanges and airflow at street level. However, few have considered its potential as a means of moderating building energy demands at the scale of the city street in urban settings.

There is a great need for research that links these indoor and outdoor perspectives that accounts for the timing of the urban climate effects in relation to the timing and nature of building occupation. This study represents an initial exploration of these relationships. It examines building energy loads associated with office and residential uses and how these are affected by two urban effects:

1. that on atmospheric properties, by employing an 'urbanised' climate files and;
2. that on solar receipt as a result of mutual shading provided by building groups arranged as rows to form streets.

The simulations presented here are based on an archetypical street found in the City of London, the area consists of parallel rows of office buildings, where although external conditions are moderate, internal heat gains are significant and in its current form daytime cooling need dominates.

### 2.1 Moorgate

Moorgate is a street comprised of office buildings that is occupied during office hours. There is little street vegetation, and traffic patterns match the patterns of work-based travel. Its street geometry is relatively compact ( $H/W \geq 1$ ), with a regular, well-defined symmetrical arrangement of high-end office buildings of similar height, volume and construction. Thus, it may be described as homogeneous in its form, activity levels and occupation patterns (Fig. 1). As such, it provides an ideal setting in which to consider how street form can regulate solar access and affect building energy management. The properties of this street and its buildings are used here to design a simulation experiment to evaluate these relationships.

## **3. Methodology**

For this study we examine the conditioning loads of two building functions, a typical UK office (Class Use B1, hereafter referred to as Office) and a modern apartment style dwelling (Class Use C3a, hereafter referred to as Residence). Initially these are examined in a stand-alone, isolated

setting and then as an element in a series of buildings arranged into street configurations, known as urban canyons. These canyons are described by their average  $H/W$  ratio. The aim here is to identify performance patterns associated with both the building and urban form alongside the building functions. Both building functions (Office and Residence) have contrasting patterns of occupation and will experience different types and magnitudes of internal and external energy gains and losses.



Fig. 1. North facing photo of case study area e Moorgate the city of London e taken during a typical working day around midday.

Two building forms are employed (labelled A and B) to represent typical building forms found in the UK (Fig. 2). Both forms have identical floor areas, external glazing (on one façade only) and building envelope fabrication, but are distinguished by their foot- print, building height and orientation, based on the direction of the glazed facade. The energy performances of these building forms are simulated for both functions (office and residential). To account for the suitability of the building floor area for use as Office and Residence, the two building forms were subdivided into appropriately sized sections (Figs. 2 and 3). Both sections (shaded and non-shaded) areas have been assigned identical building properties and occupation profiles associated with each function. This has done to ensure that the adjacent zones have identical thermal properties. However, whilst these adjacent zones are included in the simulations, the results are not presented.

Apart from changes in dimensions, the physical properties of both building forms (types A and B) are identical (Table 1) but they have different occupation patterns (Fig. 3 and Table 1) that affect internal conditions. For this study both the heating and cooling season operates year round; and



infiltration is set at 0.25 ac/h [17], with airflow at 10 L per second per person [18].

A cooling load has been included for Residence, even though these could be managed through ventilation strategies. This decision was made to:

1. limit the variables that are modified;
2. highlight the relationship between external climate effects and building activity patterns, and;
3. to draw attention to overheating risk as a cooling load requirement.

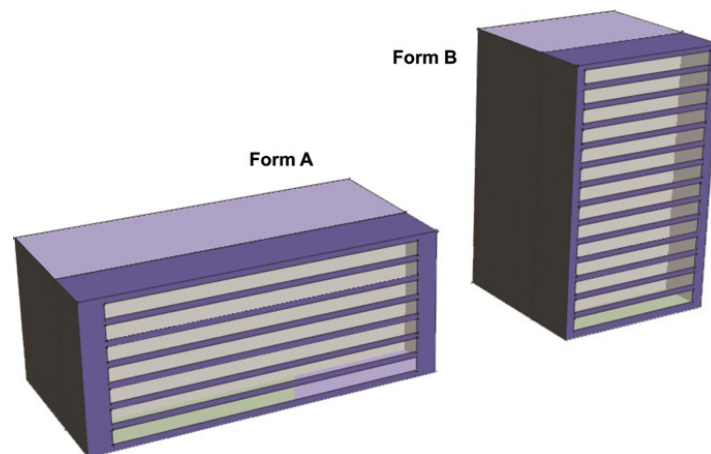


Fig. 2. Form A and B. The pale areas represent the boundary conditions (the adjacent zones). These areas are assigned identical properties and building parameters as the zones under investigation, however whilst these buildings are included in the simulation runs the results are not presented.

The thermal dynamic simulation tool IES VE is used to evaluate building energy performance. It was chosen for its ability to simulate the performance of multiple buildings within an urban context and comprehensive feature set. It accounts for shading effects and the radiation exchanges between buildings. The effects of climate are accounted for in the associated weather files that describe the typical patterns of temperature and wind, for example. IES allows various site conditions to be set. For example, terrain type (rural, semi-urban or urban) and levels of wind exposure (sheltered, normal or exposed). These settings determine general parameters such as rate of heat loss, which is connected to the weather file wind direction, speed & height above ground alongside temperature, and daytime radiation level. Depending on selection the convection coefficient determines the 'general effects' of the environment at the building surface. These parameters are connected to the indoor conditions by the surface heat balance and assume level of exposure or sheltering effect dependant on terrain specified. IES VE is widely used in industry and academia and is validated for use in dynamic thermal modelling in the UK.

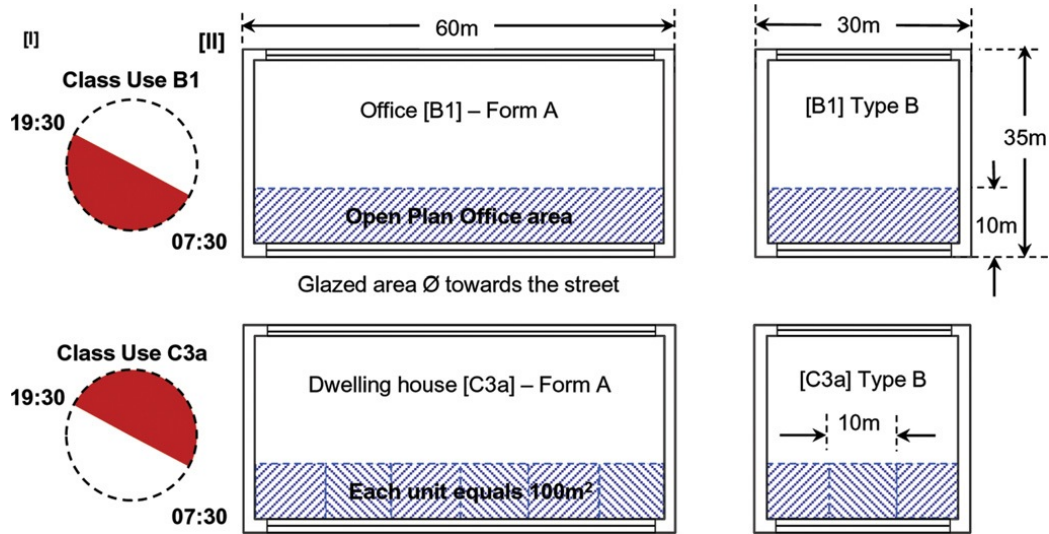


Fig. 3. The occupation schedules associated with Office (top row) and Residence functions [i] and floor plans for the two building forms (A and B) and two building functions (Office and Residence). The shaded sections represent area under investigation.

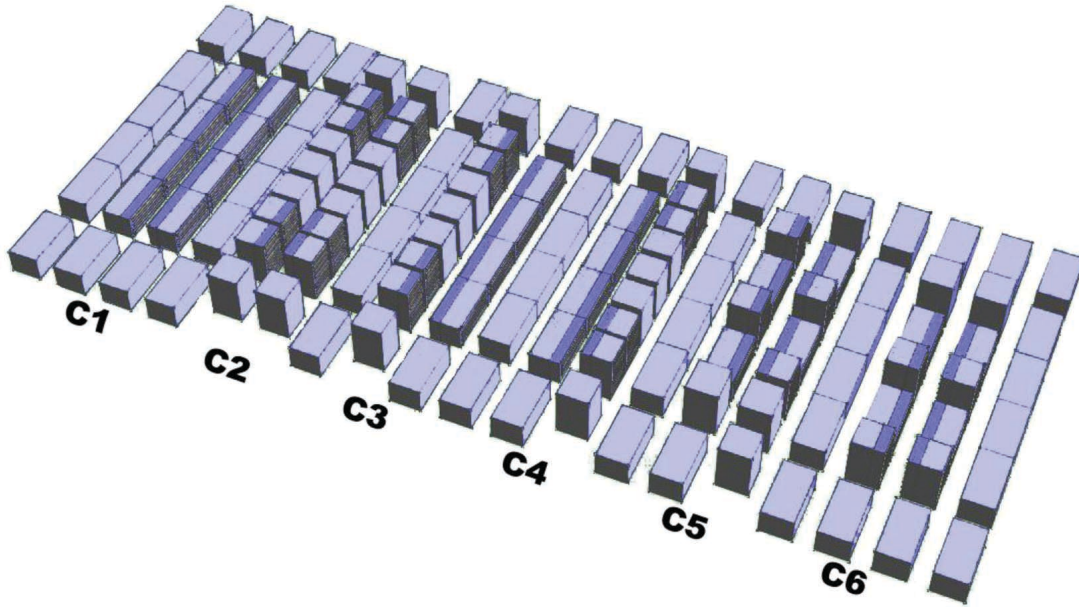
Building Properties	Type A	Type B
Floors above ground	7	14
Net Total floor area (m <sup>2</sup> )	4000	4000
Building Footprint (m <sup>2</sup> )	600	300
Total height (m)	24.5	49
Width (m)	10	10
Length (m)	60	30
Surface area front face(m <sup>2</sup> )	1470	1470
Surface area roof (m <sup>2</sup> )	600	300
Glazing (street face only) (m <sup>2</sup> ) (60%)	882	882
Volume (m <sup>3</sup> )	14700	14700
<b>U-values (W/m<sup>2</sup>K) - UK Building Regulations L2A-2010</b>		
Flat Roof (Bitumen & stone chippings)	0.25	
External / Party Wall (Masonry)	0.35/ 0.2	
Floor	0.25	
Window/SHGC	2.2 /0.637	
<b>OCCUPANCY PROFILE</b>	<b>Class Use B1 (Office)</b>	<b>Class Use C3a (Residence)</b>
persons/m2	0.1	0.4
Occupation hours (holidays are treated as a working day)	7:30 am & 19:30 pm working week only, weekends are not included	19.30 pm & 7:30 am working week, 24 hour occupation at the weekend; a nocturnal reduced level of activity between 11:30 pm & 6:30 am
internal gains (kWh/m <sup>2</sup> /yr)	80	30
Heating set point/ set back (°C) (CIBSE 2006)	19-Dec	19-Dec
Cooling set point/ set back (°C) (CIBSE 2006)	23/28	23/26 (threshold temperature)

**Table 1:** Building properties and Occupancy Profiles for the two form A and B, and functions B1 and C3a are taken from current guidelines and legislation and previous studies [21-24]

### 3.1 Establishing the urban context



For this study six street canyons (C) representing a variety of realistic urban settings were created from the two standard building types (A and B) arranged as two parallel rows (Fig. 4). These canyons are 240 m long and 20 m wide the glazed facade of each building faces toward the building opposite. Each of the canyons is oriented north to south so the individual building elements (A or B) are oriented east (E) or west (W), that is  $A_E$ ,  $A_W$ ,  $B_E$  and  $B_W$  (Table 2). These six canyons are placed within a larger street system such that each of these canyons are surrounded by other buildings that represent the urban environment. As with the adjacent zones (Fig. 2) all buildings are given the same thermal and radiative properties.



**Figure 4:** Geometric arrangement for the 2 building forms (A and B) arranged along the six canyon configurations (C1 – C6). The pale buildings represent the boundary conditions i.e. the surrounding system, adjacent zones and infill buildings. Whilst these buildings are included in the simulations the results are not presented.

The work here considers energy performance in relation to street form (as represented by the six different configurations above) and two building functions (Office and Residence). Each canyon contains the same floor area, has identical wall and glazed surface areas and fabrication but altering the building functions changes the timing of occupation and the level of internal gains (Table 1).

Canyon No.	Mean H/W	Building Type
C1	1.2	A
C2	2.4	B
C3	1.8	B opposite A
C4	1.8	A opposite B
C5	1.8	Staggered (A and B)
C6	1.8	Mirrored (A and B)

**Table 2:** Description of the arrangement of the 2 building forms in the six canyon configurations

Each building under study can be identified by its building form and canyon number (Figs. 2, 4

and 8, and Table 3). To establish a base for comparison, the performances of the buildings in their urban setting are compared against a reference building, defined here as that of an identical building in a stand-alone setting. To act as a reference, fully exposed to solar receipt, no shading devices are assigned to the glazed façade. Whilst façade design offers opportunities to optimise condition loads, the study presented here focuses on the role of urban form as an energy management parameter for initial design stage consideration before any additional optimisation is implemented.

Canyon Layout	East Facing					West Facing		
Building	1	2	3	4	5	6	7	8
C1 H/W 1.2	A	A	A	A	A	A	A	A
C2 H/W 2.4	B	B	B	B	B	B	B	B
C3 H/W 1.8	B	B	B	B	A	A	A	A
C4 H/W 1.8	A	A	A	A	B	B	B	B
C5 H/W 1.8	B	A	B	A	A	B	A	B
C6 H/W 1.8	A	B	A	B	A	B	A	B

**Table 3:** Building type and orientation of glazed façade within each street orientation

### 3.2 Weather files

The climate conditions in this study are based on two UKCP09 TRY generated data weather sets [19] for Heathrow: the ‘normal’ climate based on the period 1961-1990, which is used as the baseline for climate projections and; the climate forecast for 2050 based on the A1FI emission scenario. These represent the current and future background climate conditions. These files have been modified to account for the urban effect using the method outlined by Kershaw et al. [20]. The effect on hourly air temperature ( $\Delta T_x$ ) is accounted for by the following seasonal and diurnal adjustments:

For winter

$$\Delta T_x = \left( \left( \frac{1 + \cos(x\pi/13)}{2} \right) \times (\Delta T_{max} - \Delta T_{min}) \right)$$

then after 13:00

$$\Delta T_x = \left( \left( \frac{1 + \cos(\pi + (x - 13)\pi/11)}{2} \right) \times (\Delta T_{max} - \Delta T_{min}) \right)$$

For summer

$$\Delta T_x = \left( \left( \frac{1 + \cos(x\pi/14)}{2} \right) \times (\Delta T_{max} - \Delta T_{min}) \right)$$

then after 14:00

$$\Delta T_x = \left( \left( \frac{1 + \cos(\pi + (x - 14)\pi/10)}{2} \right) \times (\Delta T_{max} - \Delta T_{min}) \right)$$

Where  $\Delta T_{max}$  and  $\Delta T_{min}$  represent the magnitudes of the maximum and minimum temperature differences recorded between the Heathrow site and a central London site during summer and

winter. The magnitude of  $\Delta T_{max}$  and  $\Delta T_{min}$  was varied according to cloud cover based upon observations [21,22]. These equations produce an urban effect with a minimum at 1 pm in the winter and at 2 pm in the summer. The new ‘urban’ temperature ( $T_{Ux}$ ) then is equal to the background value ( $T_x$ ) plus the urban temperature effect ( $\Delta T_x$ ),

$$T_{Ux} = T_x + \Delta T_x$$

Based upon observations this new temperature incorporates the variations in wind-speed and in cloud cover that modulates the magnitude of the urban temperature effect. Fig. 5 demonstrates the typical diurnal variation in air temperature between the background climate and the urbanised climate. The figure also shows the UHI maximum intensity as a nocturnal effect.

This methodology was used to create urbanised weather files that may be used by IES VE. Three climate sets are used here:

1. the current background climate, based on the Heathrow data file;
2. the ‘urbanised’ climate, based on adjustments above and;
3. the urbanised climate in 2050, based on the application of the urban adjustments to the 2050 Heathrow file.

Dynamic building thermal simulations are performed on the two building types (A and B) used for Office and Residence functions in a stand-alone and urban (canyon) settings using these files. To examine the potential for a ‘form first’ approach, individual buildings in the urban context are compared against the same building in a stand-alone setting and canyons are compared against the equivalent energy use by the same buildings, in a stand-alone setting.

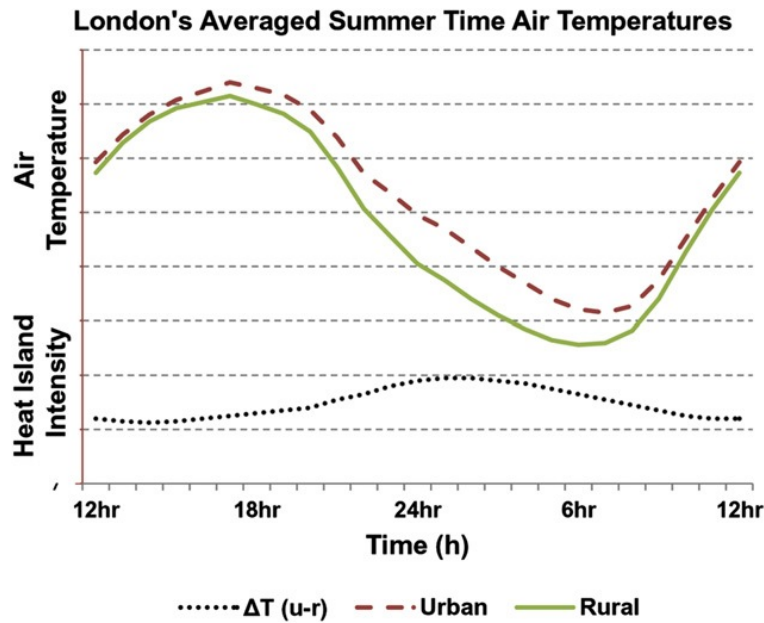


Fig. 5. Typical diurnal variation of London's averaged urban and background dry bulb temperature

(January & August).

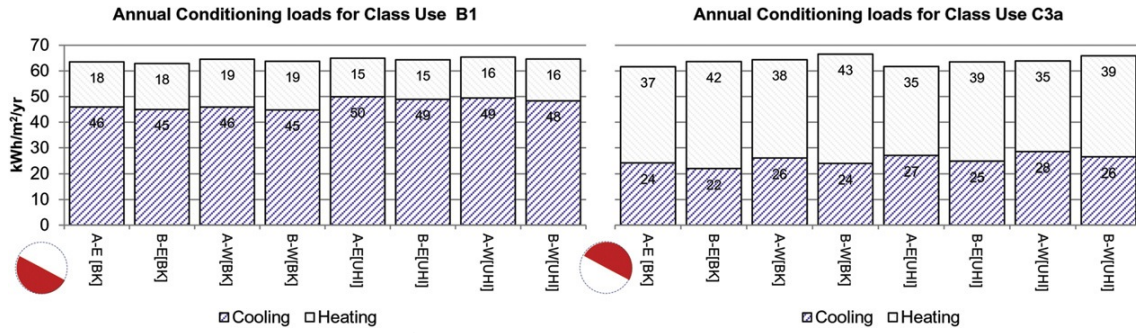


Fig. 6. Annual cooling loads (kWh/m<sup>2</sup>/yr) for the stand-alone reference buildings – forms A or B, (E and W) Ø, for both the background [BK] and urbanised [UHI] climates.

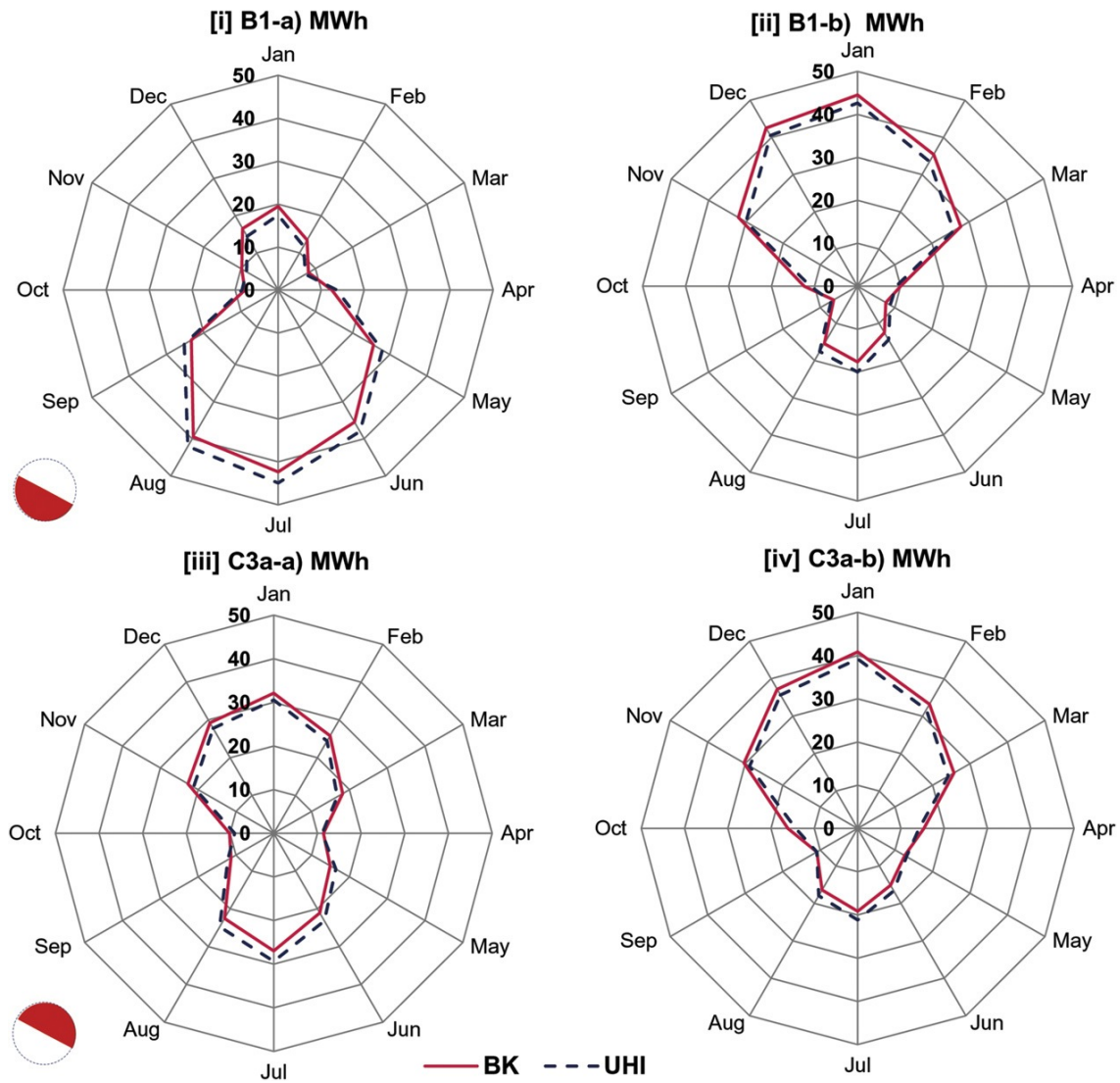


Fig. 7. Monthly heating and cooling loads (MWh) for the reference buildings A<sub>E</sub> for the two class uses (B1 and C3a), the two climate files [BK] and [UHI], both with a) and without b) internal gains.

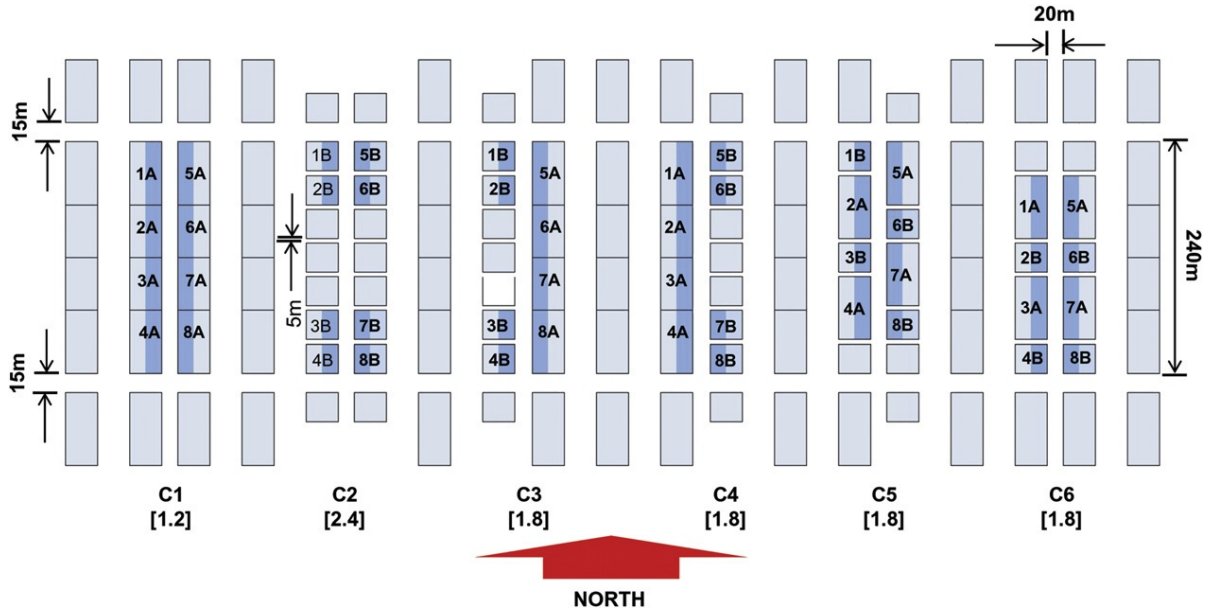


Fig. 8. Building and canyon layout. Each building can be identified by its canyon number [C1-C6], building reference number [1-4] east facing [5-8], west facing and building form [A or B]. The non-shaded buildings represent the boundary conditions i.e. the surrounding system and infill buildings.

## 4. Results

The results demonstrate the annual heating and cooling demands ( $\text{kWh/m}^2$ ) and show how these vary according to each of the variables under consideration. For clarity the results are also shown as a percentage difference when compared against the reference building. It is worth noting at the outset that the occupation pattern of Office is not limited to sunlight hours, and that of Residence is not limited to nighttime hours. Also while the Office has no weekend occupation, the Residence has a diurnal activity pattern with reduced levels of activity between 11:30 pm and 6:30 am.

### 4.1 Conditioning loads for the stand-alone reference buildings

Fig. 6 shows the annual heating and cooling loads ( $\text{kWh/m}^2/\text{yr}$ ) for the all buildings in their stand-alone setting for the current climates (both background and urbanised weather files). The results confirm that the Office energy demand is in line with the UK energy benchmark guidelines for office building types [23] and the measured annual energy consumption [24]. The urban effect is to increase the cooling load and decrease the heating load, but the former dominates as the urban air temperature effect is greatest at night (Fig. 5), when the building is usually unoccupied. Note the cooling load is almost constant for building type and orientation. The impact of the change of use from Office to Residence is shown clearly in the shift of the load from an emphasis on cooling to heating, resulting in a greater urban effect because of the correspondence of this demand with the development of the nighttime heat island (Fig. 5). Note that there is also greater variation among the buildings depending on both type and orientation. Overall, the sum of the loads differs little between the Office and Residential use in this situation ( $64 \pm 2 \text{ kWh/m}^2/\text{yr}$ ).

In these stand-alone settings, building forms (A & B), orientation (E & W) and climate file have a relatively small impact on performance patterns. However there is a cooling load dependency that relates to the solar path, and the timing of the building occupancy. Note that the loads for east-facing Offices are slightly greater than those for west-facing and that the reverse is the case for



Residences. These differences highlight the moderating effects of the internal gains, which are greater for the Office occupancy and dampen the effect of the external gain from solar access.

#### 4.2 The role of internal gains

The role of internal gains as a driver for conditioning loads has been widely reported in the energy management literature [25-27], where their significance has been shown to be dependent on many aspects of the building design including the building function and climatic conditions. To isolate the urban effect in this study, we first examine the role of the building function generating internal gains that have an impact on building energy performance.

Street	Climate	Office (kWh/m <sup>2</sup> /yr)					Residence (kWh/m <sup>2</sup> /yr)				
		East-facing		West-facing		Street reduction	East-facing		West-facing		Street reduction
C1 [H/W 1.2]	Background	52	±0.5	53	-	18	54	-	55.5	±0.5	13
	Urbanised	<b>53</b>	-	<b>53.5</b>	<b>±0.5</b>	<b>19</b>	<b>54</b>	-	<b>54.5</b>	<b>±0.5</b>	<b>15</b>
C2 [H/W 2.4]	Background	50	±1	50.5	±0.5	21	57.5	±0.5	59	-	11
	Urbanised	<b>50</b>	<b>±1</b>	<b>50.5</b>	<b>±0.5</b>	<b>22</b>	<b>55.5</b>	<b>±0.5</b>	<b>56.5</b>	<b>±0.5</b>	<b>13</b>
C3 [H/W 1.8]	Background	57	-	46.5	±0.5	19	60.5	±0.5	51.5	±0.5	12
	Urbanised	<b>58</b>	-	<b>46</b>	-	<b>20</b>	<b>60</b>	-	<b>49.5</b>	<b>±0.5</b>	<b>14</b>
C4 [H/W 1.8]	Background	46	-	57.5	±0.5	19	51.5	±0.5	62.5	±0.5	11
	Urbanised	<b>45.5</b>	<b>±0.5</b>	<b>58</b>	-	<b>20</b>	<b>49</b>	-	<b>61</b>	-	<b>14</b>
C5 [H/W 1.8]	Background	52	±4	53.5	±2.5	17	56.5	±3.5	59	±4	10
	Urbanised	<b>52.5</b>	<b>±4.5</b>	<b>53.5</b>	<b>±2.5</b>	<b>18</b>	<b>55.5</b>	<b>±3.5</b>	<b>57</b>	<b>±4</b>	<b>12</b>
C6 [H/W 1.8]	Background	51	-	52	-	19	55.5	±1.5	57	±1	12
	Urbanised	<b>51</b>	-	<b>52.5</b>	<b>±0.5</b>	<b>21</b>	<b>54</b>	<b>±1</b>	<b>55.5</b>	<b>±1.5</b>	<b>14</b>

**Table 4:** Averaged kWh/m<sup>2</sup>/yr cooling load for each orientation set for C1-C6, alongside deviation from the average and % reduction against the reference canyon for the two building functions B1 and C3a

Fig. 7 shows the monthly distribution patterns of the sum of the heating and cooling loads for the Office and Residence with a) and without b) internal gains using the background and urbanised weather files. All other variables are kept constant. Only results from A<sub>E</sub> (form A building oriented to the east) are shown as they are representative of all results. In the absence of internal gains, the patterns reflect the climate of London with cool winters and mild summers. The urban temperature effect reduces the need for heating in the winter and increases the need for cooling in the summer, but the difference is slight. Including internal gains has a dramatic impact on the distribution of energy loads over the year. This impact is clearest for the Office, which shifts the dominant energy need from winter-time heating to summer-time cooling. By comparison the impact for the Residence is to distribute the energy need more evenly between summer cooling and winter warming periods. The reason for this difference is the nature of occupancy. For the Office, the daily cycle of business (and maximum internal gain) corresponds with the period of maximum external energy gain, in particular solar energy transmission through the glazed facade. On the other hand, for the Residence the occupation pattern generates energy in the evening and morning hours, when external gains are relatively small. The urban temperature effect does not increase the length of either the heating or cooling season but influences loads level during the peak cooling and heating periods. More generally, including internal gains associated with occupancy patterns moderates the direct influence of climate on building performance. In the following, internal gains are included in assessing the energy performances of buildings and of streets.



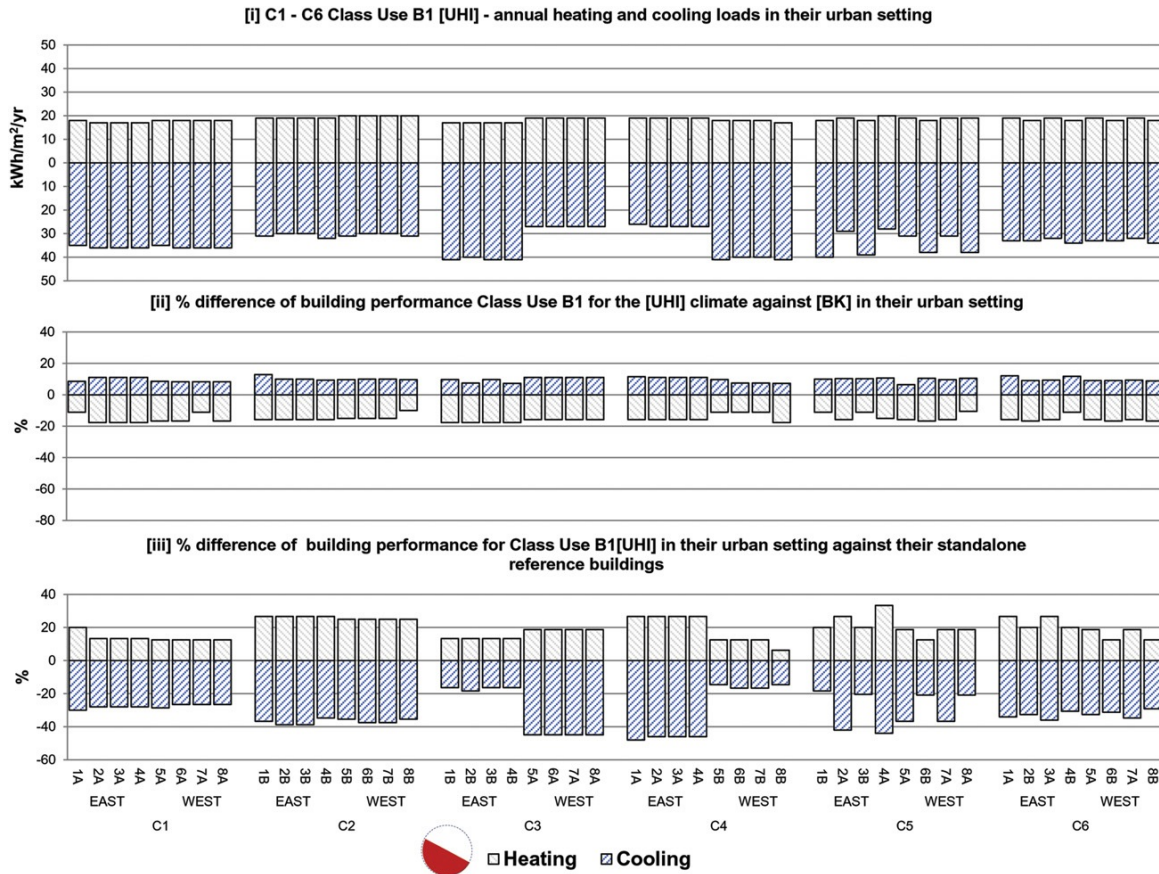


Fig. 9. Annual heating and cooling loads for the Office in different street configurations: [i] annual energy load ( $\text{kWh/m}^2/\text{yr}$ ); [ii] the percentage difference in the energy loads obtained using the urbanised and background climate files and; [iii] the percentage difference in the energy loads when the buildings in their street setting are compared with the same buildings in an isolated setting.

#### 4.3 Conditioning loads for the buildings in the urban context

Fig. 8 shows the layout of the buildings and street canyons used in this study. Each building is given a code that identifies its canyon (C1 to C6), its ‘address’ and building form (e.g. 4A). These codes are used to identify the energy performance of individual buildings in the figures that follow.

The primary impact of the urban setting is to reduce the external energy gain by shading, which reduces the transmission of solar energy into the building, lowers surface temperatures and the magnitude of convective and radiant heat loss from the building. This effect is significantly greater than the increased gain that results from higher urban air temperatures. Table 4 shows the average building conditioning loads along each side of the street configurations. Note the reduction in energy need when compared to the standalone settings (Fig. 6): the conditioning load of buildings in the street is within the range of  $52 \pm 11 \text{ kWh/m}^2/\text{yr}$  compared to  $64 \pm 2 \text{ kWh/m}^2/\text{yr}$ . However, the impact is greater for the Office (reductions of between 17 and 22%) than for the Residence (reductions of 10-15%). In addition the urbanised climate always results in an increased net canyon load over the background climate, this discussed in more detail in Section 4.5.

#### 4.4. Conditioning loads of buildings in streets

The timing of the urban effects has different impacts on the performance of the buildings along streets that depends on their function (see Office (Fig. 9) and Residence (Fig. 10) functions). To highlight the impact of the controlling factors, the results are shown as [i] heating and cooling loads (kWh/m<sup>2</sup>/yr) for the 1990 urbanised climate, [ii] the percentage difference when compared with the 1990 non-urbanised background climate and, [iii] the percentage difference when compared with the same buildings in a stand-alone setting using the urbanised climate file.

Figs. 9[i] and 10[i] show similar performance patterns, although as before the proportion of the heating and cooling loads differ reflecting the building functions, with the largest range found in the cooling loads for both building functions, reflecting the diurnal nature of solar heating and street geometry. On the other hand the heating load shows very little variation between the different streets, although this range is increased for the Residence function. The results for streets C1 (H/W = 1.2) and C2 (H/W = 2.4) reflect their symmetrical arrangement and different aspect ratios. The superior performance of C2 is due to greater shading which reduces its cooling load. The output performance patterns of the asymmetrical streets (C3 and C4) shows this effect clearest: the lower buildings experience a dramatic reduction in their cooling load as a result of shading provided by the taller buildings across the street. The performances of the buildings in canyons C5 and C6 respond to their geometry, which consists of irregular building heights on either side of the street that are either offset (C5) or aligned (C6). Although both streets have the same exposed surface area, their performance patterns are not equal with C5 showing the greatest range between buildings. This illustrates the significance of the urban setting on building performance.

Figs. 9[ii] and 10[ii] shows the influence of the UHI by comparing the performances above with those if the background climate file is used. The results show the UHI has a greater effect on the cooling load of Residential function because  $\Delta T_x$  is largest at night when the building is occupied. For Office buildings the impact on the cooling load is smaller owing to its daytime activities. In contradiction to this the Office function shows the largest reduction in heating loads, as Section 4.1 this reflects the reduced level of nocturnal activity for Residential function. Finally, Figs. 9[iii] and 10[iii] compare the performances of buildings shown in Figs. 9[i] and 10[i] against the same building (and function) in a stand-alone setting (the reference building). It is clear that the effect of daytime shadowing as governed by H/W is more significant to managing building performance than the UHI effect.

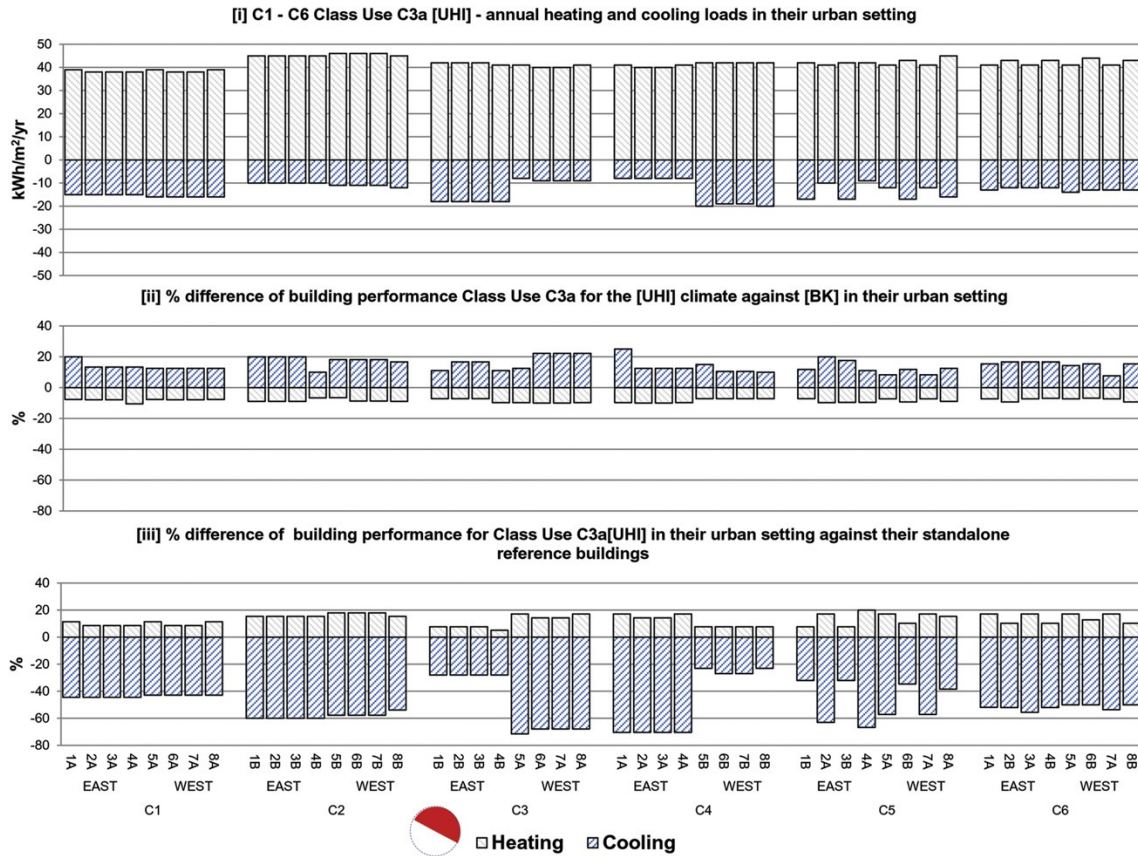


Fig. 10. Annual heating and cooling loads for the Residence (see Fig. 9 for description of graphs).

#### 4.5. Conditioning loads of streets

Fig. 11 shows the monthly totals (MWh) of both the heating and cooling loads for all buildings within their street configurations, for the current (1990) and target (2050) year urbanised climates. Both heating and cooling loads of all streets for both climate files and building functions follow distinct patterns that correspond to H/W, which regulates the solar gain: the street with the smallest H/W of 1.2 (C1) experiences the highest summer cooling load and lowest winter heating load; street C2 (H/W = 2.4) has the lowest summer cooling load and the highest winter heating load and; streets C3 to C6 (H/W 1.8) falling between the two. The shift from heating to cooling loads does not vary with H/W but moves later in the year for the 2050 target year.

Fig. 11 clearly demonstrates the relationship between building function and mean H/W ratio. For the Office, the performance is dominated by the cooling load, which increases with warming trends. Here the influence of H/W ratio is found to be most pronounced during the peak-cooling season with the differences in H/ W showing little influence on the heating load. The heating load for the Office is diminished with warming trends. On the other hand, the effect of H/W is seen throughout the year under current and future climates for the Residence. However this is largest for the current UHI, where the heating load is dominant. The influence of the target year UHI on these loads can be seen to influence both the peak-heating load, which is lowered, and the peak cooling load, which is increased. As the heating demand is reduced the over- heating risks are also increased.

These results are consistent with urban climate research that shows higher H/W values correspond to lower daytime surface temperatures. As an urban climate parameter, H/W

determines the level of solar shading and consequently affects building energy gain and conditioning loads. These results have implications on retrofit methodologies, which are discussed in the following section.

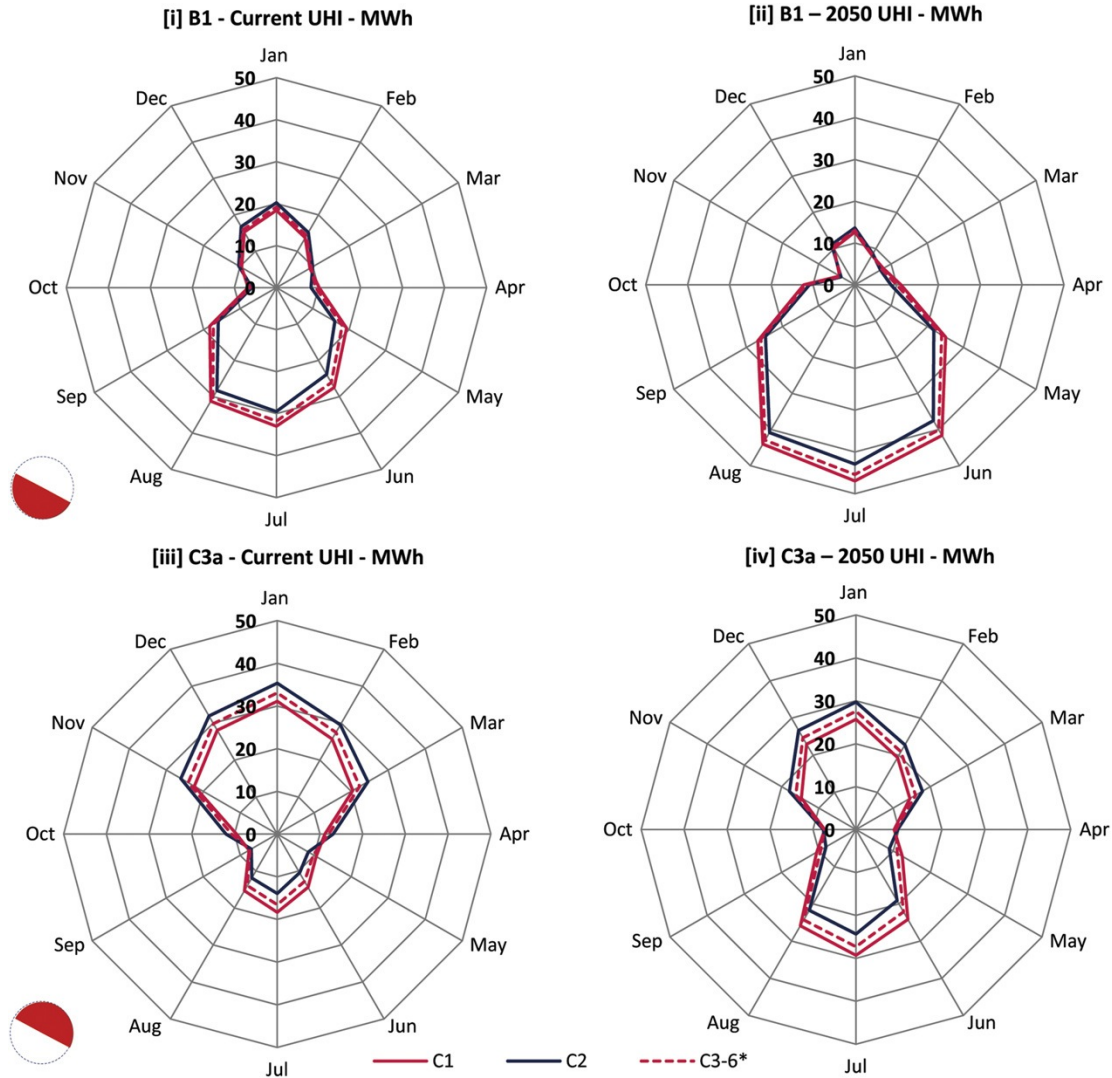


Fig. 11. Averaged monthly heating and cooling rates (MWh) for C1 to C6 street configurations for the two building functions Office and Residence in both the current (1990) and target (2050) urbanised climates. The configurations (C3-C6) are presented as an average.

## 5. Discussion

In an isolated (stand-alone) setting each building type has nearly identical overall energy performance however the partitioning into heating and cooling loads depended upon the nature of occupation. Whereas the dominant Office energy need was for cooling, that for Residence was heating. Examining their performances in a street setting showed that: 1. the daytime shadowing effect improved the energy performance of the Office (reduced cooling load) but worsened that of Residence (increased heating load) and; 2. the canopy level UHI effect (which is mainly a night-time phenomenon) improved the energy performance of the Residence (reduced heating load) but worsened that of the Office (higher cooling load).



The largest effect of the urban setting was a reduced cooling load (or overheating risk) for the Office and the Residence but that for the latter is minimal under current climate conditions. The UHI effect is small when compared with the shadowing effect for the buildings studied here, which emphasises the importance of street design as a building (and urban) energy management parameter. These results highlight the significance of solar access, which is regulated by the urban setting, in any refurbishment strategy. They also draw attention to the very different energy needs associated with different building functions.

For the future climate scenario, the management of condition loads for the Residence is more complex than that for the Office, under current occupation patterns. The expected warmer air temperature increases the risk of overheating. For the Office function, the potential increase in cooling load could be offset through modifying the urban form (such as by increasing the H/W of streets) to increase the mutual shading of buildings. However, managing the urban form to address the needs of buildings with a more complex occupation and activity pattern (such as Residence) is more difficult. In the current climate the heating load dominates and retaining the solar gain during the daytime is beneficial, such that a lower H/W to maximise solar access is desirable. To maintain the beneficial effects of wind shelter and the nighttime UHI, which reduce the heating load, higher H/W values are preferable. Oke [28] suggested that an H/W of between 0.6 and 1.0 would be best for mid-latitude cities. However by 2050 the heating and cooling loads will require more equal consideration and higher H/W values may be warranted.

This has implications of the suitability of the location for this building function for target scenarios that can impact on target reductions. An increase in warming trends makes managing over-heating risks a priority; a less significant warming trend keeps managing the heating load the prime importance. And whilst these loads can be managed through the mutual relationships that develop in urban areas, further evaluation of retrofit technologies is required.

## **6. Summary and conclusions**

The purpose of this study was to examine the suitability of urban settings (represented by streets) for buildings with different occupational patterns associated with their function. Here we examined the changes in condition load demands when a street comprised of Office buildings (with a dominant daytime use) is transformed to one comprised of Residences (with a dominant nocturnal use). To compare the performances of the buildings in streets of varying height to width ratio, the number of variables was limited: the same building forms were used and the timing and levels of internal loads was modified to represent Office and Residence needs. Simulations were performed using IES VE, a widely employed thermal dynamic model that is suitable for examining the energy performances of multiple buildings simultaneously. It accounts for the energy exchanges between buildings and for the sheltering effects on wind that occur in urban areas. The effect of the urban area on air temperature was included by modifying the current (1990) and future (2050) weather files to reproduce the urban heat island effect with a maximum after sunset.

The results highlight the importance of considering street geometry as a ‘form first’ evaluation of the suitability of an urban area for buildings that are designed for particular functions. For the Office with a daytime function the primary need is to dispose of internally generated heat. Relatively narrow streets ( $H/W \gg 1$ ) performed best by providing shade that limited additional external gains and reduced the cooling demand. Although the effect is also to raise the night-time outdoor air temperature the impact of this is relatively small both in terms of magnitude and timing. On the other hand, if these buildings were to be converted to Residence function, the urban heat island reduces the heating need at night, which is beneficial. However, the needs of the

Residences are more complex than those of offices and the nature of occupancy is less well defined. A form-first approach could address some of these issues by considering the optimum use of building space along a street. This is particularly the case where the street form is largely fixed or undergoes marginal changes over time.

The results here may be best described as exploratory. The study has been structured to examine the energy performances of buildings when placed in juxtaposition and the implications of changing building function on that performance. Whereas there is a great deal of research on both the energy performances of individual (often isolated) buildings and on urban climate effects, there has been little work that has attempted to link the indoor and the outdoor urban climates. The work suggest that a 'form first' approach offers energy management opportunities that are over- looked using 'fabric first' approach. An examination of the urban setting of a building, in conjunction with its intended use, at an early design stage would help in decision-making for improved energy performance. Moreover, it would help in the development of an urban energy management strategy that is area-based.

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